User Guide

1 ECHO USER MANUAL 2

1.1 ECHO FRONT END 2
1.2 ECHO INFORMATION WINDOWS 2
1.3 THE CELL PLAN WINDOW 2
1.4 THE COVERAGE WINDOW 3
1.5 THE SERVICE WINDOW 4
1.6 THE DIVERSITY WINDOW 4
1.7 THE C/I WINDOW 5
1.8 THE USER INCOME WINDOW 6
1.9 THE ECHO MENU COMMANDS 6
1.10 INDIVIDUAL OPERATOR SELECTION 9
1.11 PARETO WATCHER FORMATION 10
1.12 OPTIMISATION CONSOLE OUTPUT 11
1.13 ONE-OPT PROCESSING 12

2 SCENARIO FILE FORMATS 13

2.1 SCENARIO DESCRIPTION FILE FORMATS 13
2.2 CONTROL FILE FORMATS 21
2.3 OUTPUT FILE FORMATS 24

1 ECHO User Manual

This document serves as a brief instruction manual for the ECHO optimisation tool. It describes the operation of the ECHO GUI and describes the steps involved in carrying out the more common tasks.

1.1 ECHO Front End

Figure 1 - The ECHO Front End GUI

The front end GUI is presented on starting the application. The menus and buttons are divided into groups that perform similar functions. The buttons and fields have tool tip help that gives a brief description of the operation associated.

The Current Network Metrics and the Best Network Metrics display the values for the most important of the metrics for the networks under investigation. These values are updated during optimisation and manual adjustment of the network. The constraint satisfaction icon indicates whether the current network satisfies the limits defined in the scenario file.

1.2 ECHO Information Windows

The ECHO tool has six windows that graphically represent features of the network. Each window uses a 2-dimensional plan view of the scenario as a basis. We will describe each in turn.

1.3 The Cell Plan Window

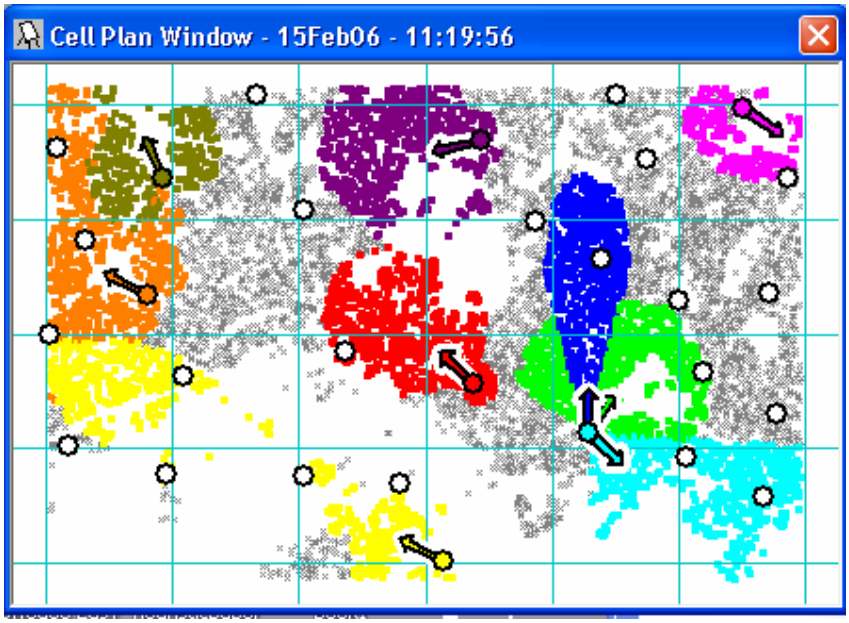


Figure 2 – The Cell Plan window

The cell plan window shows the current cell plan for the network. Each sector is displayed as an arrow that starts at the site used by the sector. The length of the arrow is proportional to the power of the sector, while the direction of the arrow represents the applied bearing of the sector.

Un-used candidate base sites are shown as open circles, while RTP are shown as small grey crosses. For each served user, we place a small coloured square at the employed RTP. The colour of the square corresponds to the relevant serving sector. The un-served users are not shown. The light blue grid lines are placed 1 km apart. The basis for the lines is the centre of the scenario, rather than any given co-ordinate system.

1.4 The Coverage Window

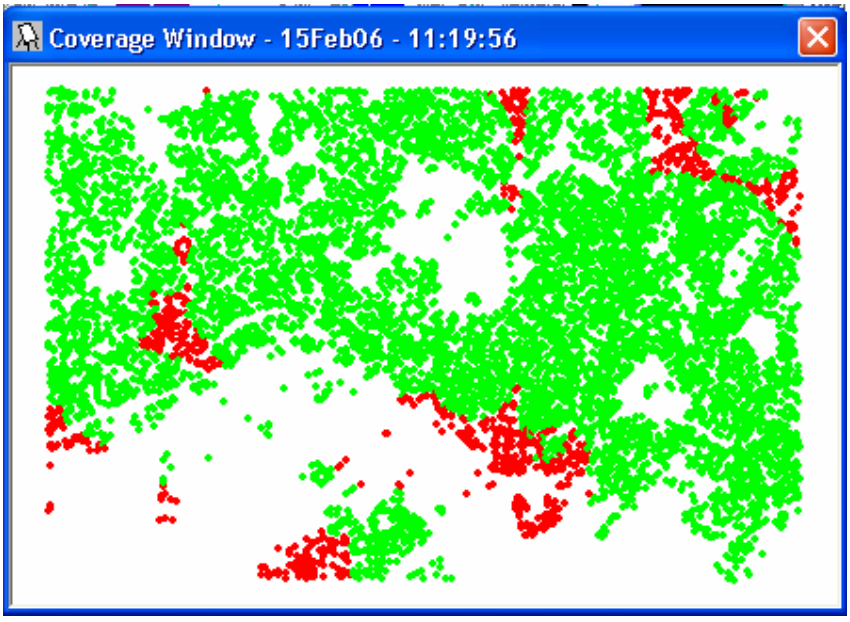


Figure 3 – The Coverage window

The coverage window displays the coverage status of all the users. For each user, we select a representative RTP. If the user is covered, we place a green circle at this point. If the user is not covered, a red circle is used.

1.5 The Service Window

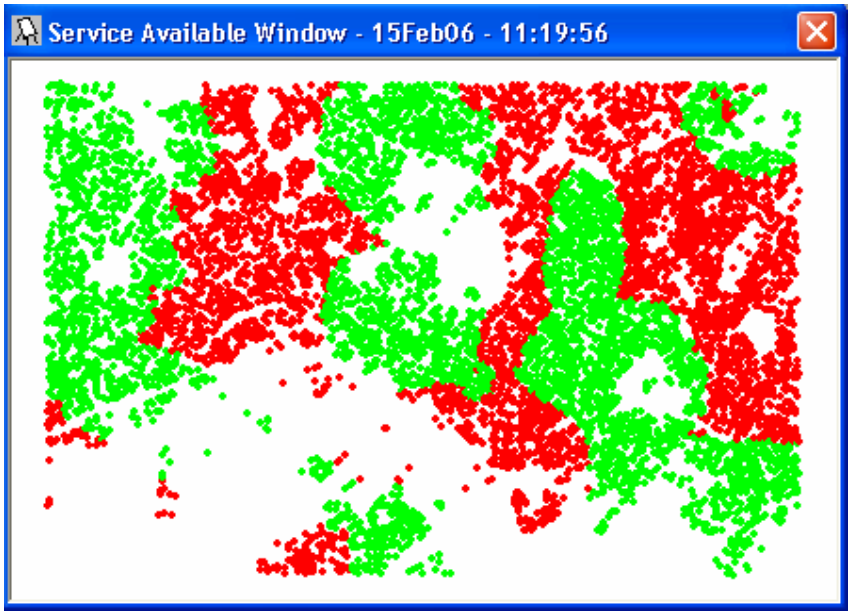


Figure 4 – The Service window

The service window is similar in appearance to the coverage window. However, in this case, where the user is served, the symbol is green. Where the user is not served, a red circle is used.

1.6 The Diversity Window

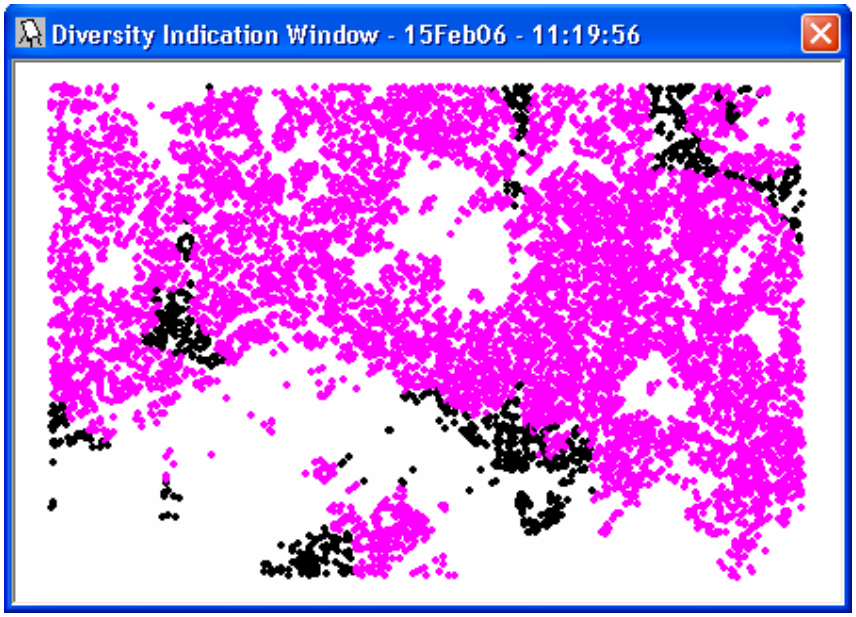


Figure 5 – The Diversity window

The diversity window displays those users to whom a diverse solution could be offered. The colour code for each user is determined by the number of sites that have sectors that can provide a signal above threshold. The colours are as follows:

Number of Sites	Colour
0	Black
1	Black
2	Red
3	Green
4	Blue
5	Yellow
6	Magenta

Table 1 – The Diversity Colour Mapping

Hence, the fraction of coloured (i.e. non-black) symbols represents the diversity fraction associated with the network.

1.7 The C/I Window

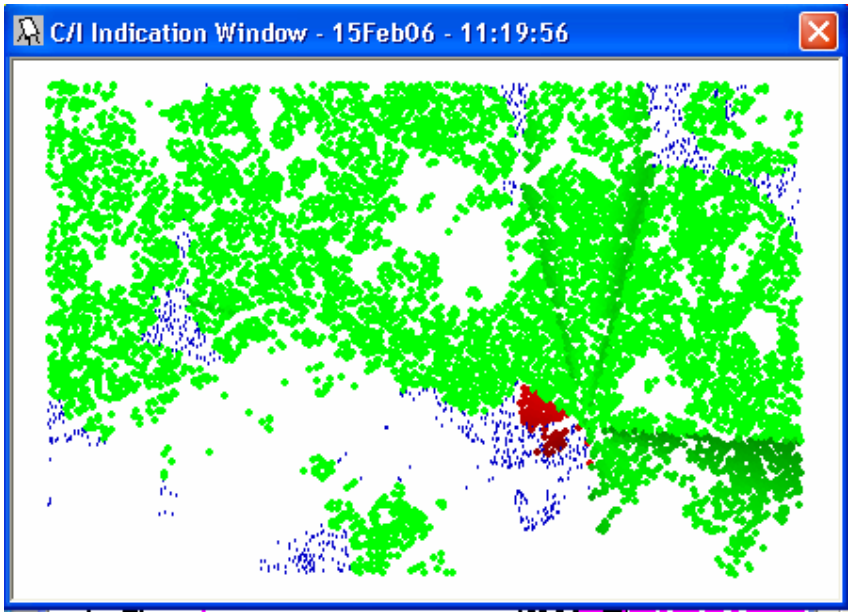
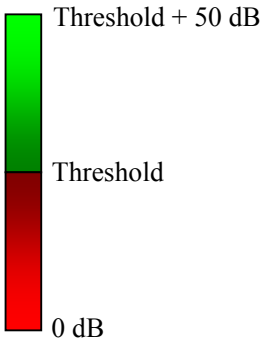


Figure 6 – The C/I window

The C/I window displays the signal to interference ratio for all the users. The colour of the symbol for each user is determined on a sliding scale as below:



Hence, users with a ‘bright’ green symbol are well above the C/I threshold, while ‘bright’ red symbols indicate users whose signal is of the same order as the interference.

1.8 The User Income Window

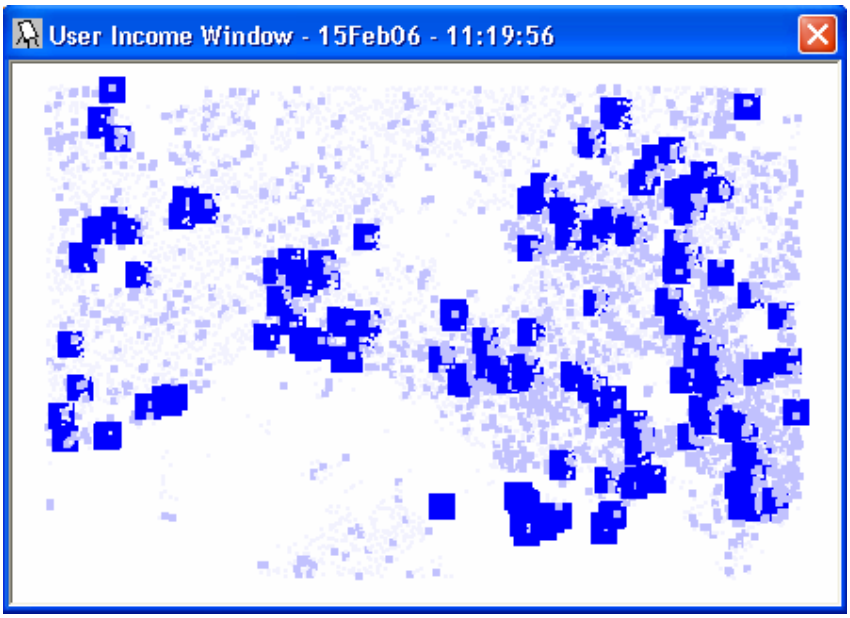


Figure 7 – The User Income window

The user income diagram is static during optimisation, as the symbols in the window are determined by the scenario, rather than the network.

For all the users in the scenario, we determine the maximum and minimum expected subscription income. We then determine each individual users position on the scale between the maximum and minimum income. This relative income value is used to determine the size and intensity of the blue colour for the user’s symbol. Hence, the larger and deeper the colour, the higher the income that user will generate if it is serviced by a sector in the network.

1.9 The ECHO Menu Commands

Figure 8 – The File Menu

The File menu allows the user to select and de-select the scenario under test.

The open scenario command allows the user to select which scenario to load. A standard open file dialog is presented for the selection of a ".prj" file. The selected scenario is loaded into the ECHO data structure and made ready for investigation. Note that where a scenario is already present, it will be removed in favour of the new scenario.

The close scenario command clears the current network and scenario, and resets the data structures.

The exit command will quit ECHO.

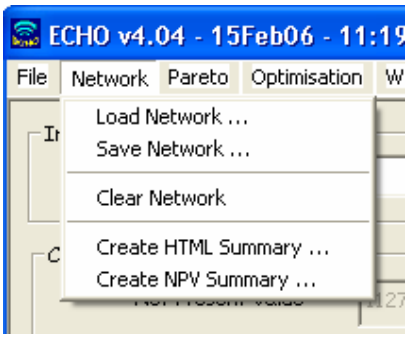


Figure 9 – The Network Menu

The Network menu deals with the input/output for the current network in the defined scenario. Note that the network commands will not do anything unless a scenario has been loaded.

The load network command allows the user to select an existing network from disk. The network is loaded, and the GUI updated with the metrics for the network.

The save network command writes the current network to disk. The default file name is made up from the current time and date.

The HTML Summary provides an informational document that describes the features of the current network and contains a snapshot of the information windows described above. These summaries are also generated automatically at the end of each optimisation stage. Create NPV Summary provides a document which details the NPV matrix.

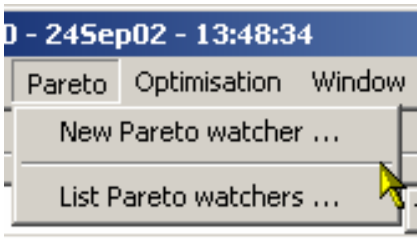


Figure 10 – The Pareto Menu

The Pareto menu allows the user to define and review the Pareto watchers. Note that Pareto watchers can be defined independently of whether a scenario has been loaded.

The new Pareto watcher class brings up the Pareto definition dialog (see below). This allows the user to define a Pareto watcher that will operate for the rest of the ECHO session. The list Pareto watchers command displays a list of the currently defined watchers in a special dialog explained below. This command allows the user to review the Pareto watchers already defined.

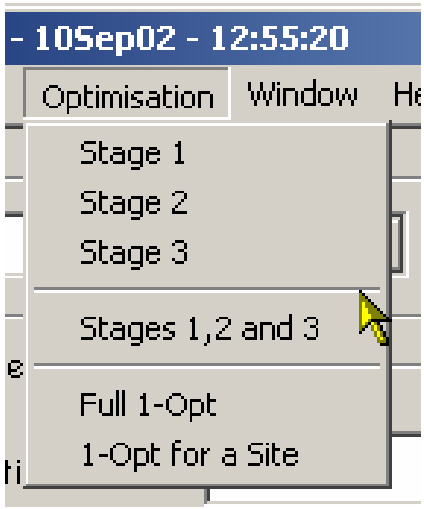


Figure 11 – The Optimisation Menu

The Optimisation menu allows the user to start the optimisation routines.

The Stage 1, Stage 2 and Stage 3 commands each start the appropriate optimisation stage on the current scenario and current network. Note that if the current network does not meet the hard constraints defined in the scenario, then the Stage 3 command will not do anything.

The combined stages command simply runs the three stages in order using the network at the end of each stage as the starting point for the subsequent stage.

The user can also decide to start the 1-Opt processing from this menu. Note that the Full 1-Opt process may take a long time to complete. The 1-Opt for a Site command allows the user to select a single site for 1-Opt processing using the site selection dialog described below.

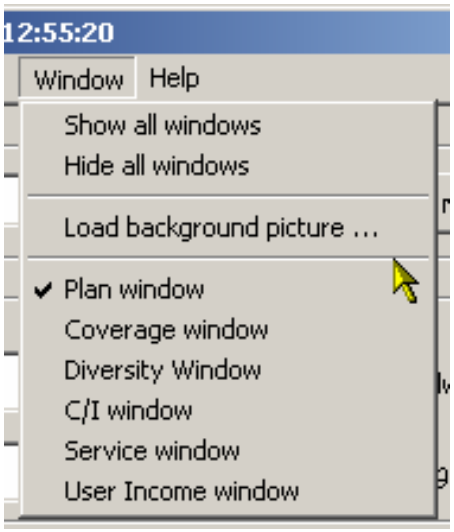


Figure 12 – The Window Menu

The Window menu allows the user to manipulate the supplementary display windows that are created by the ECHO code.

The show all windows command brings all the supplementary windows to the desktop, while the hide all windows command removes them all from the desktop. The load background picture command allows the user to select a bitmap image to display as a backdrop for all the information windows.

The individual window commands allow each window to be toggled individually. The check mark next to each window indicates the visibility status of the window.

1.10 Individual Operator Selection

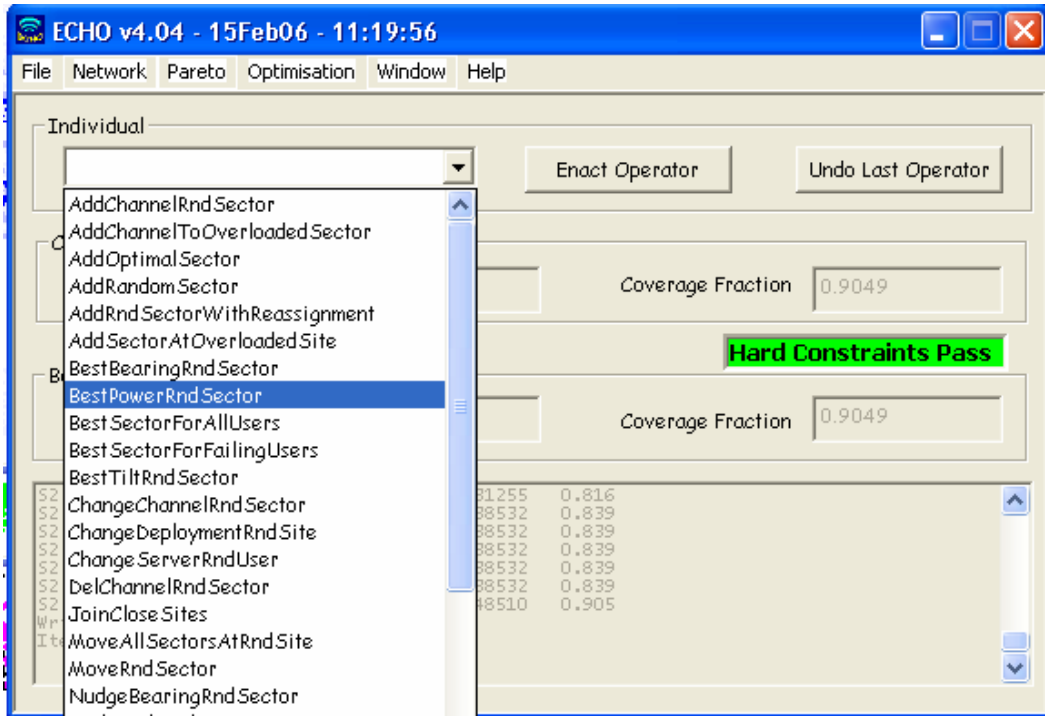


Figure 13 – The Operator Selection / Usage Interface

The user can select any one of the Network Operators in order to change the current network loaded. Once the operator is selected, the operator is enacted once by clicking on the Enact Operator button. The display windows and the metric values on the GUI will be updated to reflect the changes to the network.

If the user wants to immediately undo the changes made by the last operator, the Undo Last Operator button can be used. Note that this undo applies only to the most recently enacted operator. Once undone, the operators cannot be undone again – hence the Undo button only allows for one level of back tracking.

1.11 Pareto Watcher Formation

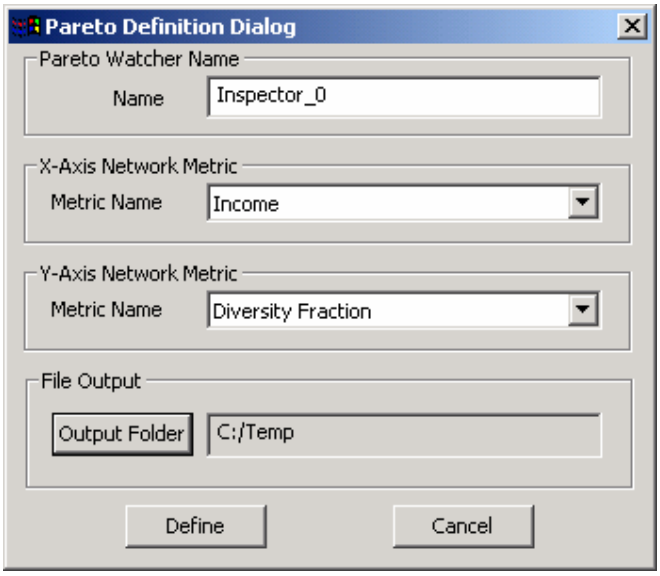


Figure 14 – The Pareto Watcher Definition Dialog

In order to define a Pareto Watcher, the user must select the two metrics to watch during optimisation. The metrics are selected from the drop-down lists.

The user can also change the name of the Pareto Watcher. This name is used as a unique identifier when the Pareto front network files are written to disk. The output folder for these files (which defaults to the scenario output folder) can also be selected by clicking on the Output Folder button.

When all the information is correct, the Pareto Watcher is created by clicking on the Define button. If the Cancel button is used, no Pareto Watcher is defined.

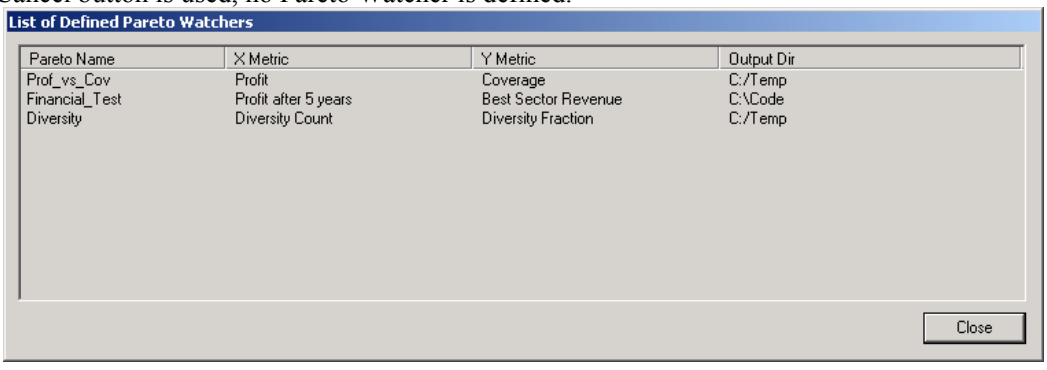


Figure 15 – The Pareto Watcher Review Dialog

In order to see what Pareto watchers have already been defined, the review dialog lists the currently defined watchers. Note that there is no way to delete already defined watchers.

1.12 Optimisation Console Output

We present an example of the output from the console window below:

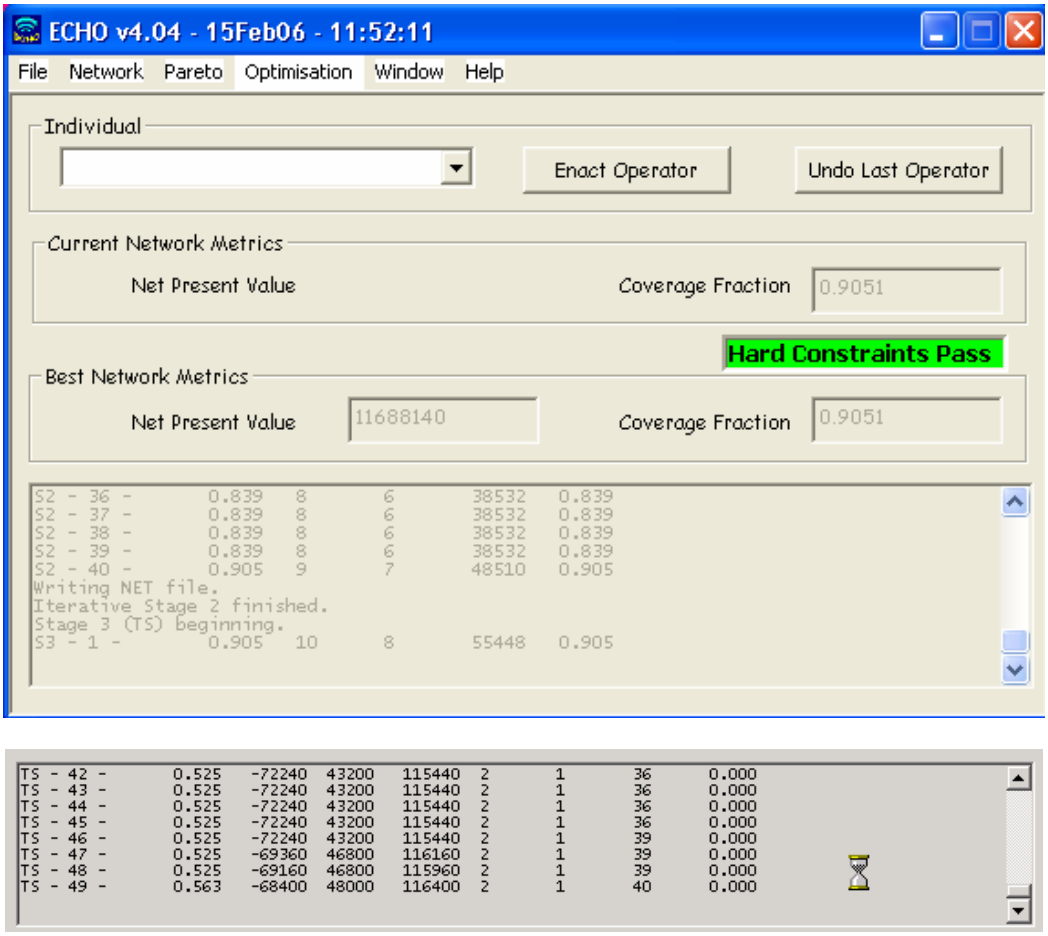


Figure 16 – The console optimisation output

The GUI interacts with the user during optimisation by writing a limited set of network statistics to the console window at the bottom of the dialog as well as updating the information windows. The order of the data is as follows:

The optimisation method indicator
- S1 – Stage One
- S2 – Stage Two
- S3 – Tabu Search (i.e. Stage Three)

The iteration number
The coverage fraction for the current network
The number of base sectors defined
The number of base sites employed by the deployed sectors
The diversity count – This is the total number of sectors that can be 'seen' by all users
The diversity fraction – This is the fraction of users who can 'see' more than one sector

These metrics are updated automatically during optimisation. For some of the stages, messages are posted into this window to reflect the current operation of the optimisation.

1.13 One-Opt Processing

If the user selects the 1-Opt for a Site command from the Optimisation menu, a Site Selection dialog is present as below:

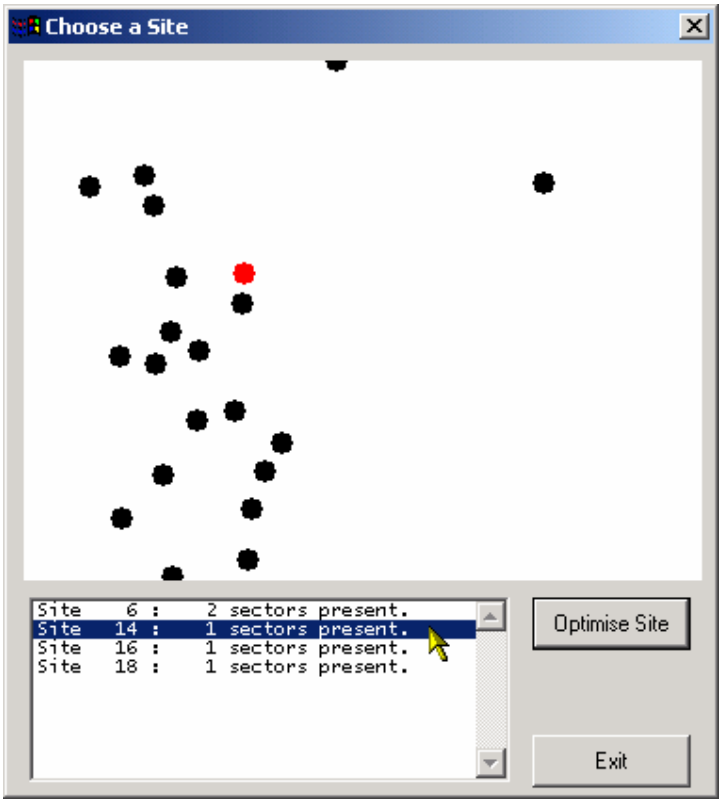

Choose a Site
Site 6 : 2 sectors present.
Site 14 : 1 sectors present.
Site 16 : 1 sectors present.
Site 18 : 1 sectors present.
Optimise Site
Exit

Figure 17 – The Site Selection Dialog

The user can select any of the populated sites in the list box at the bottom left of the dialog. The selected site will be highlighted in red on the site distribution map. If the user wants to optimise the sectors at the site, the Optimise Site button should then be clicked. If no site is suitable for optimisation, or the user does not wish to optimise any sites, the Exit button can be used.

2 Scenario file formats

Here we detail the file formats used to describe the ECHO scenario, the output files used to represent the networks and the files that represent the particular network metrics associated with that network.

All input files and the network file are standard ASCII files that can be modified using a standard text editor. Columns are delimited with spaces or tab characters. The network metric files are simplistic HTML files that can be opened with standard HTML rendering software[1].

We list the files in approximately the order they are read by the ECHO code.

2.1 Scenario description file formats

2.1.1 Antenna List File

This file provides a list of base-station and user antenna types. For each we define the path to the antenna's radiation pattern file and the (time-varying) costs associated with using and maintaining one instance of the antenna.

```
BaseAntenna {
   Antenna_ID = 5
   PatternFile                                    =
d:\data\Antennas\BaseAntenna_90.baf
   CapEx=[5000,  4347,  3781,  3291,  2867,  2500,
2500, 2500]
   OpEx=[250, 217, 189, 165, 143, 125, 125, 125]
}

UserAntenna {
   Antenna_ID = 1
   PatternFile                                    =
d:\data\Antennas\UserAntenna_UHG.uaf
   CapEx=[250, 187, 141, 106, 81, 62, 62, 62]
   OpEx=[13, 9, 7, 5, 4, 3, 3, 3]
}
```

The Antenna_ID is a unique positive integer identifier associated with that model. Both BaseAntennas (those used by sectors) and UserAntennas (the consumer premise equipment) are defined here. The ID numbers for each set are separated, meaning that a BaseAntenna with an ID of 1 also allows a UserAntenna with an ID of 1.

2.1.2 Antenna Pattern File

We begin with a typical BaseStation antenna file:

```
CS2_Sec(15)
G 21
L 0

STC       0            0
STC       5            -
3
STC       9            -
10
STC       15           -
25
STC       16           -
35
STC       90           -
35
```

[1] For example: Mozilla FireFox, Internet Explorer, Safari, etc.

```
SAC         0               0
SAC         7.5             -
3
SAC         13.7            -
10
SAC         14              -
30
SAC         180             -
40
```

This is a standard BaseAntenna description. The first line is a name for the antenna[2] and the next lines list the boresight gain and loss figures (in dB). The second value (the L, or loss, number) is used to include any power losses that are of a nature that can be predicted but cannot be avoided (ie pointing errors, connection losses).

The next lines describe the antenna pattern itself. Each line starts with a description of the data contained in the next two columns. This descriptor can be one of the three values depending on whether the antenna pattern is defined in two orthogonal planes or with radial symmetry. For 'two-plane' antennas, the following descriptors apply:

- SAC – Signal Azimuth CoPolar – Here, the next column represents the opening angle on the horizontal plane in the range 0 to 180 degrees. The final column represents the loss in dB associated with such an angle.
- STC – Signal Tilt CoPolar – Now, the second value represents the angle above and below the horizontal plane in the range 0 to 90 degrees. The final value again represents the loss in dB associated with this offbeam angle.

Note that for 'two-plane' antennas, the antennas are assumed to be symmetric in both planes, so only the angular values between [0-180] for azimuth and [0-90] for tilr are recognised.

For radially symmetric antennas, the only allowed descriptor is:

- SRC – Signal Radial CoPolar – The next value is an angle off the axis symmetry, and the loss value follows.

In this case the allowed angular values are [0-180].

Similarly, we show a UserAntenna file below:

```
UHG
G 24
L 3

RC          0
    0
RC          0.9
    -3
RC          5
    -16
RC          10
    -24
RC          15
    -28
RC          25
    -33
RC          30
    -37
RC          70
    -45
RC          90
    -58
RC          180
    -58
```

[2] This data is not used by the ECHO data structure, but must be included.

After the standard name, gain and loss lines, the three allowed descriptors are:

- RC – Radial CoPolar
- AC – Azimuth CoPolar – The azimuth plane is the horizontal pattern
- EC – Elevation CoPolar – The elevation is the angle off the horizontal plane

From the defined values, a graph is drawn within the code. Each off-beam loss is then a straight-line interpolation between the two closest defined values. Where necessary, the radial angle, ψ, is calculated from the azimuth and tilt (θ, ϕ) as below:

$$\psi = TAN^{-1}\left(\sqrt{TAN^2\theta + TAN^2\phi}\right)$$

Thus, an off-beam azimuth of 10 degrees and an off-beam tilt of 5 degrees form an off-beam radial angle of 11.14 degrees.

2.1.3 Base Site Listing

A standard base site list is shown below:

```
Site{
   SITE_ID = 1
   X_POS  =      3148
   Y_POS  =      3653
   Z_POS  =      62.5

   CapEx=[30000,  26584,  23609,  21159,  19038,  17205,
17205,17205]
   OpEx=[1500, 1329, 1181, 1058, 952, 860, 860, 860]

   TrafficLimit = 270000
}

Site{
   SITE_ID = 2
   X_POS  =      3201
   Y_POS  =      5280
   Z_POS  =      171.2

   CapEx=[25000, 21584, 18609, 16159, 14038, 13205]
   OpEx=[1600, 1400, 1200, 1000, 950]

   TrafficLimit = 170000
}
```

The data enclosed between the chain brackets and pre-fixed by the word 'site' gives all the relevant detail for the one particular base site. The first line is the site identifier (a unique positive integer). The next three lines define the base site spatial co-ordinates in metres.

The CapEx array defines how much it costs to activate the base site in each period, while the OpEx array defines the yearly operating cost for this site. Again, these cost values are expressed in the monetary unit most appropriate (€, $, £ etc) and the final value in the array is used for all subsequent periods, where required for the calculation of NPV (see Section 1.1.7)

The final line, TrafficLimit, defines the traffic limitation applied to the site. This limitation may be defined by the available backhaul capacity and is expressed in kb/s.

2.1.4 RTP Type List

As stated in Section 1.1.1, each RTP has a capital expenditure and operational expenditure associated with it. While we could define these values for each RTP, this is labourious and makes scenario

adjustment overly difficult. Hence, we define RTP types. Each RTP is then assigned a type value form which it receives its financial values from this type.

Thus, we define a list of RTP types as follows:

```
RTPType{
    TYPE_ID = 0

    CapEx=[0]
    OpEx=[0]
}

RTPType{
    TYPE_ID = 1

    CapEx=[200]
    OpEx=[20,   15,
12, 10]
}
```

Again, the 'RTPType' name is followed by chain brackets that fully define each type. The ID is a unique positive integer identifier, and is followed by the financial information. In this case, we could consider type 0 to be a self-install system, whereas type 1 is an ISP-installed mast mounting.

2.1.5 RTP List

The next file to describe is the RTP list:

```
1   3148   2125
    18.3   0
6   3298   2954
    16.5   1
103 4333   3559
    35.6   1
42  1221   3591
    41.0   0
15  5634   3716
    57.1   0
23  3244   4269
    85.6   2
12  3148   4300
    87.6   0
```

Here, the columns are:

- A unique positive integer associated with the RTP
- X co-ordinate in metres from some defined origin
- Y co-ordinate
- Z co-ordinate
- RTP Type identifier

Note that all values must be defined for all RTP, and that the ordering of RTP within the file is unimportant.

2.1.6 User Type List

In a similar fashion to the list of RTP types, we define a list of User types to allow for quicker scenario manipulation. An example is shown below:

```
UserType{
    TYPE_ID = 0

    Revenue = [648]
    ConnectionCharge = [50]

    TakeRate = [0.426, 0.53, 0.622, 0.697, 0.752, 0.79, 0.815,
0.831]
    MarketShare = [0.7, 0.6, 0.55, 0.5, 0.5, 0.5, 0.5, 0.5]
    ChurnRate = [0.20]

    RequiredTraffic = [204.8]
    RequiredAvailability = [99.99]
}

UserType{
    TYPE_ID = 2

    Revenue = [550, 530, 515, 505, 500]
    ConnectionCharge = [50]

    TakeRate = [0.1, 0.23, 0.32, 0.4, 0.46, 0.49, 0.52, 0.53]
    MarketShare = [0.5, 0.4, 0.35, 0.3]
    ChurnRate = [0.10, .8, .7]

    RequiredTraffic = [64, 64, 64, 64, 128, 128, 128]
    RequiredAvailability = [99.9]
}
```

A user type defines a class of user, e.g. nomadic, household, SOHO[3], business etc. The data enclosed between the chain brackets and pre-fixed by the word 'UserType' gives all the relevant detail for the user type in question.

The first entry, TYPE_ID, is the type identification, being a unique positive integer. The second entry, Revenue, is the revenue generated from a single instance of this type of user. Although this can vary from year to year, a single entry means that the revenue for each period is the same. In a similar fashion, the ConnectionCharge is the one-off fee obtained from the user during activation.

The TakeRate is the percentage (expressed as a decimal) of users subscribing to this type of service per period. The MarketShare shows what percentage (expressed as a decimal) of the TakeRate value can be ascribed to the operator we are considering. The total percentage of all users subscribing to the operator is the product of these two values.

The ChurnRate is the percentage of subscribed users who terminate their subscription per period. It is assumed that the same number of users 'churn' from other operators to the operator under consideration. Thus, the churn rate does not affect the overall number of users, but rather the number of users who will require newly obtained CPE. It is assumed that the operator does not recoup any money on the existing CPE from users who have 'churned-away'.

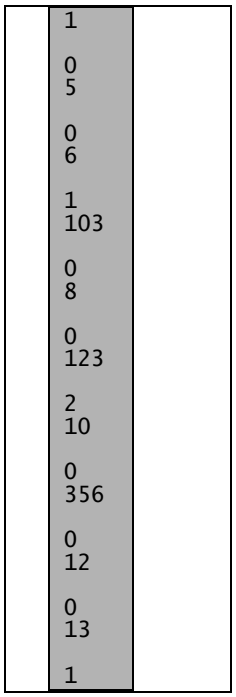
The RequiredTraffic is the contended bit-rate (in kb/s) that this type of user requires. A single figure indicates that the required service for type 0 in this instance is constant at 204.8 kb/s for the return period. This traffic value is equivalent to a 10:1 contended 2048 kb/s service. For type 1 users, a traffic upgrade will occur after 4 periods, and the required traffic increases to reflect this.

Finally, RequiredAvailability is the percentage of time for which the service must be available. This value is primarily used in rain fade type calculations, rather than an overall QOS calculation.

2.1.7 User List

With the user types defined, we need to list the users and assign them a type variable, as below:

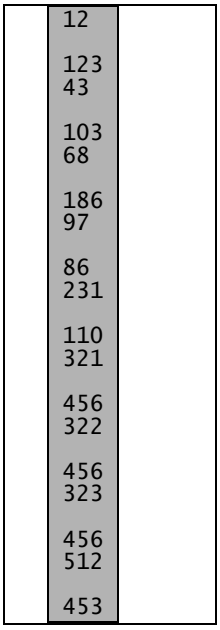
[3] SOHO is an acronym for Small Office, Home Office



The first column specifies the identifier for the specific user. The second column specifies the user type. Again, the ordering of users within the file is unimportant. Note also that the ID numbers for users, RTP, antennas and sites are all maintained separately, meaning that similar values can be used across all the lists.

2.1.8 Wire Table

With the RTP and Users defined, we can now connect them together using the file shown below:



This file specifies the wiring between users and RTP. The first column is the identifier for the RTP, and the second column gives the identifier for the user that will employ this RTP. Note that this relationship means that users can have a list of possible RTP (although only one will be selected

during optimisation). Where many users wish to use the same RTP, the users should be amalgamated into a single user instance.

2.1.9 Path Loss Matrix

With the list of Base Sites and RTP defined, we can interpret the path loss matrix file, an example of which is shown below:

```
1  1
   140.842
1  21
   126.015
1  41
   88.6006
1  12
   81.0244
2  3
   80.3191
2  21
   123.586
2  56
   124.52
2  87
   139.582
3  2
   142.717
6  4
   145.641
```

This file specifies the path between each base site and RTP. The first column is the identifier for the base site, whilst the second column identifies the RTP. The third column is the path loss value in dB. Note that this is a positive value expressing the reduction in signal strength between the two locations.

2.1.10 NPV Parameters

The next file describes some 'global' values used in the calculation of NPV:

```
DiscountRate = [0.12]

NumberOfPeriods = 8

DeploymentPeriods       =
[0,1,2]
```

Here, we specify parameters that are relevant to the calculation of the net present value. The DiscountRate is defined (as a decimal fraction) and is used to modify the yearly cash flow to produce a discounted cash flow. Note that each future income amount is discounted, meaning that it is divided by a number representing the opportunity cost of holding capital from now (year 0) until the period when income is received. This opportunity cost can arise from such external sources as the return from investing the money in another business, or the interest paid on money borrowed to build the network.

The NumberOfPeriods is the period of time over which the economics of the network will be considered. It should be noted that with high capital costs but periodic income, increasing this value would increase overall NPV. However, the predictive accuracy of the NPV calculation falls as future network technologies and requirements arise.

As detailed in Section 1.4.2, it is possible to specify when the base station equipment will be deployed. In the example shown, there is a choice of three deployment periods, i.e. base-station equipment may be deployed in periods 0, 1, and 2. The optimiser will choose the assignment in order to maximise the NPV over the entire return period. Note that the year 0 is always included in the range of values used by the optimiser, regardless of whether that value is specified in the file. This is to ensure that the network 'starts' at the correct time.

2.1.11 Spectrum Channels

The next pair of files defines the spectrum allocation for the scenario. First, we define the channels:

```
1   10      -116    4460
    17.1
2   11      -116    4460
    17.1
3   12      -116    4460
    17.1
4   10      -96     8930
    24.3
5   11      -96     8930
    24.3
6   12      -96     8930
    24.3
```

The number of channels available depends on the individual channel bandwidths, and the overall amount of spectrum available. The spectrum availability is usually dependant on region specific conditions and governmental regulation.

The first column defines the internal channel identifier, whilst the second column defines a frequency value. This value is not necessarily a strict representation of the actual frequency, but rather a channel numbering within the band.

The third column defines the minimum allowable receive power (in dBW) for each channel, the fourth column defines the bit-rate supplied (in kb/s), and the fifth column defines the minimum C/I (carrier to interferer) in dB.

Hence, in the example above, there are three frequency channels, but we define two modulation schemes for each frequency. In such a case, a sector cannot mix channels of different bit-rate.

2.1.12 Channel Rejections

With the channels defined, we must now specify the channel overlap for them:

```
1           1
0
1           2
28.1
1           3
47.1
1           4
47.1
1           5
47.1
2           2
0
2           3
28.1
2           3
47.1
```

This file defines the adjacent channel rejections, or the amount of mutual interference, for the channels defined. This has important implications for the selection and deployment of multi-channel sectors, and adjacent cell interference. The first and second columns contain channel identifiers and the third column defines the rejections in dB. Note that all overlap values are symmetric: hence, we need only define the overlap between channels 1 and 2, and the ECHO code automatically uses this value for the overlap between channels 2 and 1.

In the above, the first row shows that the rejection between channel 1 and itself is 0 dB (or 1 which indicates full overlap). The second row shows that the rejection between channel 1 and 2 is -28.1 dB (or ~0.2% overlap): for a user terminal that is tuned to channel 1, an unwanted signal (of the same

power as the wanted signal) on channel 2 will be reduced by 28.1dB. Another unwanted signal that uses channel 3 will be reduced by 47.1dB.

2.1.13 Backhaul Link List

While the scenario does not demand that the backhaul layer be defined, we present the backhaul link list file format below:

```
Link{
    SITE_A_ID = POP
    SITE_B_ID = 1

    CapEx=[22000,  17000,  13000,  11000,  9000,
7200]
    OpEx=[1000, 829, 781, 658, 652]
}

Link{
    SITE_A_ID = 4
    SITE_B_ID = 5

    CapEx=[3000, 2700, 2400, 2100, 1900, 1700]
    OpEx=[150, 130, 120, 100]
}
```

Each section (denoted by the curly brackets) defines a particular link. The ends of the link are defined using the appropriate site ID's. No directionality is implied by the selection. The special case of a link to the backbone network is denoted by using the identifier 'POP' as an ID. Each link also contains a costing with the standard capital and operational expenditure arrays.

It should be noted that the ECHO system does not check the connectivity of the backhaul link graph. It is the scenario designer's responsibility to ensure that all sites have at least one path to a POP (i.e. either a direct POP link or a connection to another site that can connect to the POP). The cost of this link may be prohibitive, but it must be included within the scenario. In the case of such a high cost link, the optimiser will only utilise the link where there are financial advantages to site activation.

Note that there is no concomitant list of backhaul nodes. It is assumed that each site requires a node, and the node that represents the POP is created by the optimiser automatically.

2.2 Control file formats

The overall scenario file uses a key/token file format. For each token required by the optimiser, the scenario designer must specify the appropriate value. All keys are defined in the format:

KeyName = KeyValue

It must be noted that key values that contain an equals sign will cause unpredictable results. In addition, all white space characters are stripped from the beginning and end of the key value. All lines not of this format will be ignored by the optimiser. Hence, section dividers and comments are allowed within the files.

2.2.1 The Project file

The project file defines the scenario in its entirety. A minimal example is shown below:

```
[Spectrum]
ChannelsFile                                =
C:\NPV\spectrum\Channels.dat
RejectionsFile                              =
C:\NPV\spectrum\Rejections.dat

[Metrics]
NPVParameters = C:\NPV\Oslo\NPV.dat

[Scenario]
AntennasFile=
C:\NPV\Oslo\AntennaList.dat
RTPTypesFile=
C:\NPV\Oslo\RTPTypeList.dat
BaseSiteData=
C:\NPV\Oslo\BaseSiteList.dat
RTPData=     C:\NPV\Oslo\RTPList.dat
PathLossData=
C:\NPV\Oslo\PathLossMatrix.dat
WireData=    C:\NPV\Oslo\WireTable.dat
UserData=    C:\NPV\Oslo\UserList.dat
UserTypesFile=
C:\NPV\Oslo\UserTypeList.dat

[Optimisation]
OutputDir = C:\NPV\Oslo\output
RandomSeed = -1997

[System]
MaxSectorPower = 0
ChannelBackoff = 3

[UserLists]
AllUsers.Required_Coverage = 0.75
```

Here, we have a scenario defined across a few files in the C:\NPV\Oslo folder. The spectrum files are in a separate folder – they may be used across many scenarios, and not be common to the 'Oslo' data set. As well as the input files we define the folder in which all output files will be saved using the OutputDir key. The network files and the HTML reports will be stored here during optimisation.

A random seed is specified. The pseudo random number generator within the code uses this to initialise itself: identical values for the input random seed will produce identical networks from a standard optimisation run. Where this value is not specified, the code defaults to an internal value. Hence, where different runs with different seeds are required, separate project files must be individually defined.

The description continues with the setting of the maximum sector power (in dBW) and the channel back-off value (in dB). These affect the overall channel power as described in the previous chapter. Finally, we specify a hard constraint that at least 75% of all users must be covered during optimisation. As mentioned above, these limits are often useful to force a cell plan where financial considerations would produce smaller networks. The optimiser makes no consistency check on these constraints, and it is the scenario designer's responsibility to ensure that it is possible for these limits to be met. If such a situation is occurs, the second stage of optimisation will never complete.

Note that the project file is read at run time and then closed – the file is not 'live'. Any changes to the file made externally will not be recognised until the project file is opened again.

Below we specify the list of all possible keys in the project file.

Property Key	**Default value**	**Description**
OutputDir	C:\temp	Directory for output of files. Directory will be created if it does not exist at run time.
RandomSeed	-12345	Random seed. Must be <0

MaxChannelsPerSector	4	Maximum number of channels present at any sector
ChannelBackOff	0	Per-channel power reduction for multi-channel sectors (dB)
MaxSectorPower	0	Maximum overall sector power (dBW)
MinSectorPower	-30	Minimum overall sector power (dBW)
MaxBoundarySignal	1000	Maximum boundary signal value (dBW). Network is invalid if the received power at the outermost users exceeds this value.
MaxUsersPerSector	-1	Maximum number of potential users that can be assigned to one sector. Negative value implies there is no limit.
AllUsers.Required_Coverage	0	Required coverage fraction for all users in the scenario.
AllUsers.Required_Diversity	0	Required fraction of users who could be offered a diversity solution.
AllUsers.Required_Service	0	Required service fraction for all users in the scenario.
UserList.N	N/A	Define acronym for each user list
<Acronym>.File	N/A	Full path name of file containing user ID's to add to this list.
<Acronym>.Required_Coverage	0	Required coverage fraction for users in the list.
<Acronym>.Required_Diversity	0	Required fraction of users in the list who could be offered a diversity solution.
<Acronym>.Required_Service	0	Required service fraction for users in the list.
BaseSiteData	Must be specified	Full path name for base site defining file
RTPData	Must be specified	Full path name for the RTP defining file
PathLossData	Must be specified	Full path name for the path loss matrix file
WireData	Must be specified	Full path name for user to RTP wiring file
UserData	Must be specified	Full path name for the user defining file
ChannelsFile	Must be specified	Full path name for channel list file
RejectionsFile	Must be specified	Full path name for channel rejection file
NPVParameters	Must be specified	Full path name for NPV parameters file
AntennasFile	Must be specified	Full path name for antenna list file
UserTypesFile	Must be specified	Full path name for user type list file
RTPTypesFile	Must be specified	Full path name for RTP type list file
LinkListData	N/A	Full path name for the list of backhaul links. Where this file is not specified, the backhaul link layer will not be considered.

All values are set to default (or not applied) if the key is missing. All other keys are ignored.

2.2.2 ECHO Initialisation file

The ECHO system has a number of parameters attached to the optimisation process, rather than any specific scenario. The program reads an initialisation file (ECHO.ini) that allows advanced users to adjust the operation of the ECHO tool. The list of key values is shown below:

Property Key	**Default Value**	**Description**
Stage1ProportionalityValue	3	Number of sectors added during stage one is "MinSectors" multiplied by this value.
Stage3Iterations	1000	Number of iterations during stage three.

Stage2Iterations	100	Limiting number of iterations during stage 2.
TSRListLength	10	Length of the TS recency list.
TSNeighbourhoodSize	10	Number of nets to generate at each TS iteration.
ClearTabuSearchRecency	0	Determines whether TS recency list is cleared between consecutive stage three runs.
ProduceFullStatistics	0	Determines level of metrics output during run. Non-zero value produces full stats.

All values are set to default if the key is missing. All other keys are ignored. A sample ECHO.ini file is shown below:

```
[System]
Stage1ProportionalityValue
= 3
Stage3Iterations = 250
Stage2Iterations = 250

ProduceFullStatistics = 1

ClearTabuSearchRecency = 1

TSRListLength = 10
TSNeighbourhoodSize = 10
```

2.3 Output file formats

The ECHO tool writes a number of files detailing the optimisation process and the networks produced. We will begin with the file format that describes the networks themselves:

2.3.1 Network file

The network file contains all the information required to fully describe the cell plan. Hence, as well as user assignments, we must include the site deployment periods and sector descriptions. An example is shown below:

```
17
0     0
1     2
2     1
3     0
[…]
5
10 0 2 -10 340
-5 3 1 4 7
12 1 1 -4 170 0
2 2 5
[…]
1202
0  1  231  12  -
79.3 Y 43.5
1  0  543  10  -
90.2 N 31.65
2 1 786 12 -113
Y 13.5
[…]
1
10
151
1
3
41
[…]
```

The sections marked […] are removed for clarity, and represent repeats of the format of the previous line.

The file starts with the total number of sites, followed by that number of pairs of values. Each pair expresses the Site ID and the deployment period for that site. This is followed by the number of sectors in the cell plan. The sectors are then described with the parameters in the order:

- Sector ID – This is automatically assigned by the optimiser, and is a unique ID for the sector
- Antenna ID – The ID number of the antenna in use
- Site ID – The site ID for the location of the sector
- Power – The sector power in dBW
- Bearing – The horizontal plane direction of the sector in degrees – 360 degrees is due north.
- Tilt – The tilt off the horizontal plane for the sector – 0 degrees is horizontal.
- Channel Ordinal – The number of channels in use for the sector
- Channel ID's – The list of channels in use, referenced by the channel's ID number.

After the list of sectors, we have the number of users defined in the file. This can be different from the total number of users in the scenario: where users are not defined, they will be set to a default state (no selected RTP, no selected antenna and no serving sector). Each user entry consists of the following values:

- User ID – The unique identifier for the user.
- Antenna ID – The identifier for the particular CPE in use
- RTP ID – A number representing the RTP utilised.
- Sector ID – The serving sector for the user.
- Signal Strength – The received power in dBW.
- Traffic Status – A (Y/N) value representing whether the user's traffic requirement is satisfied by the serving sector
- C/I Ratio – The C/I ratio value in dB

Note that the last three values for each user are actually determined by the model. Hence, when the network file is read by ECHO, these values are ignored and the system recalculates the values. In addition, the Antenna, RTP and Sector ID numbers each may be –1. Such a value represents that the respective choice has not been made for that user.

With the end of the user definitions, we come to the locked sector listing. The first number gives the number of locked sectors that are to follow. The subsequent lines list those sectors by ID. Similarly, the next value is the number of locked users and then a list of that many user ID numbers. Note that this is also the format used for defining locked sectors and users. Where no locked sectors or users are present, this section can be omitted.

It should be noted that while it is possible to manually edit the network file, it is not recommended without a thorough knowledge of the ECHO system. Errors in the file can lead to the ECHO session going into a hung state.

2.3.2 HTML Network Description

An example of a typical HTML output file is shown at the end of this document.

Essentially, the HTML output file is a rendering of the network file defined above in a more readable format. The first table lists the metrics associated with the network. The coverage and service levels are fractional values, where a value of one represents that all users are included. All these metrics are familiar except perhaps the maximum boundary signal. A (location-based) convex hull of all the RTP is calculated by the ECHO tool, and this value represents the maximum RF power received over this hull. Thus, it represents the maximum RF power that will be encountered by neighbouring systems. As

mentioned previously, the value can be limited during optimisation in order to reduce unwanted signal bleed into adjacent networks.

We continue by listing the sites along with each site's occupancy (the number of sectors at the site) and deployment period in a table. The next table goes on to list the sectors present along with their parameters. Where defined, the locked users and sectors are also listed.

Along with the network description, we include data about the scenario against which the network has been designed and tested. Hence, we tabulate what is essentially the information in the project file, along with the number of sites, RTP, antennas and users present. We also calculate three particular metric values:

- Maximal user expected bandwidth – This is the maximum total traffic required by all users were they all to subscribe. It represents a 'sizing' of the scenario with respect to traffic.
- Maximal user expected revenue – In a similar fashion, this represents the maximal income that could be expected were all users in the scenario to use the service.
- Average subscription probability – This is the value for the subscription rate when averaged over all users present.

Note that as all these values are time-dependent, the maximal values over all periods are used in the summations. The file continues by detailing any hard constraints imposed and comparing the given limits with the current network performance. The next section is a rendering of the initialisation file, with a listing of the optimiser switches and parameters.

Finally, the network is presented graphically in the standard six methods: the cell plan, the coverage map, the diversity map, the service map, the C/I map and the user income indication. These representations are more fully described in the user guide section of this document.

2.3.3 HTML NPV Description

An example of an NPV HTML file is shown at the end of this document.

With the inclusion of the NPV metric, we have included an output file that allows users to follow the detailed calculations involved and compare user types and the time development of income and expenditure. The file begins by showing the number of periods, the number of deployment periods and the number of user types involved. The cumulative discount rate is then displayed against the periods.

For each user type, we show the number of subscribers in the scenario of this type, along with the development of the input parameters over time. This is followed by the number arrays of N_{BOY}, N_{EOY}, N_{New}, N_{Aver} and N_{CHN}.

Note that those period columns marked with an asterisk are deployment periods.

The next entries describe the effective expenditures on antennas and RTP for the type. As each user has a free choice of antenna and RTP, users of the same type can utilise different equipment. In order to arrive at a final figure for the expenditure for the given user type we therefore calculate the appearance rate for each type of equipment within the user type, and use this relative appearance to calculate overall cost figures for the CPE and RTP.

As well as the expected revenue for the type, the effective values for the equipment are multiplied by the appropriate number of users at this deployment period to give an overall per-user-type CapEx and OpEx figure.

After describing all the user types present, the next table describes the base station data for the NPV. Here, we list the CapEx and OpEx for both the sites and the sectors at the sites. By design, CapEx is

zero for all non-deployment periods, but OpEx continues over all periods. Finally, we list the cash flow and the discounted cash flow arising from the given figures. As mentioned previously, the sum of this final row is the overall NPV figure.

2.3.4 Network HTML File Example

Below is a typical network HTML file. The file is described in more detail in Section A.3.2 of this document.

Network Summary

Number of sites in use	5
Number of sectors deployed	22
Coverage	0.649693
Service	0.595614
Net Present Value	634269
Diversity fraction	0.649693
Diversity count	17480
Max Boundary Signal	-96.115

Site ID	Number of Sectors	Deployment Period
0	5	0
1	5	0
2	0	0
3	0	0
4	0	0
5	0	0
6	3	0
7	0	0
8	6	0
9	0	0
10	0	0
11	3	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0
17	0	0

Sector ID	Site ID	Antenna ID	Power	Bearing	Tilt	Number Of Channels	Channel ID's

0	1	4	-10.0	250	0	2	2 1
1	1	4	-14.0	90	-17	2	3 1
2	1	4	-12.0	161	-8	1	4
3	1	4	-12.0	217	-14	1	3
4	1	4	-13.0	30	-6	2	2 4
5	0	4	-10.0	102	0	2	1 4
6	0	4	-11.0	330	0	2	4 1
7	0	4	-10.0	184	-8	2	1 4
8	0	4	-10.0	250	6	1	2
9	0	4	-10.0	135	10	1	2
10	11	4	-14.0	292	0	2	3 4
11	11	4	-10.0	330	-12	2	1 2
12	11	4	-10.0	85	0	1	3
13	6	4	-10.0	200	0	1	2
14	6	4	-10.0	303	0	2	3 4
15	6	4	-10.0	62	0	1	1
16	8	4	-10.0	60	0	1	4
17	8	4	-10.0	37	0	1	2
18	8	4	-10.0	96	0	1	1
19	8	4	-15.0	285	0	1	4
20	8	4	-10.0	284	-2	1	1
21	8	4	-10.0	289	0	1	3

No Locked Users.

No Locked Sectors.

Scenario Summary

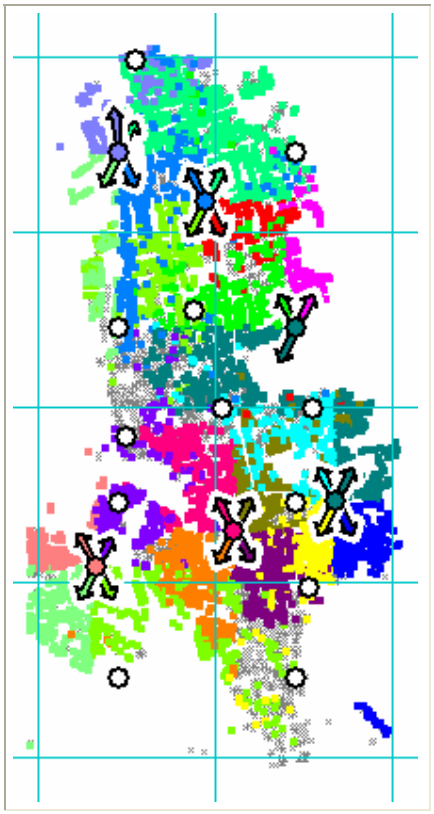
Project File Name	D:\Echo4\Oxford\Oxford_TestC.prj
Default output directory	D:\Echo4\Oxford\output_TestC
Initial RNG seed	-1997
Maximum sector power	-10
Minimum sector power	-30
Boundary signal level	1000.00
Number of users	5381
Number of potential sites	18
Number of reception test points	5381

Number of hub antenna models	1
Number of user antenna models	1
Maximal user expected required bandwidth	1894112
Maximal user expected revenue	2582880
Average subscription probability	0.32

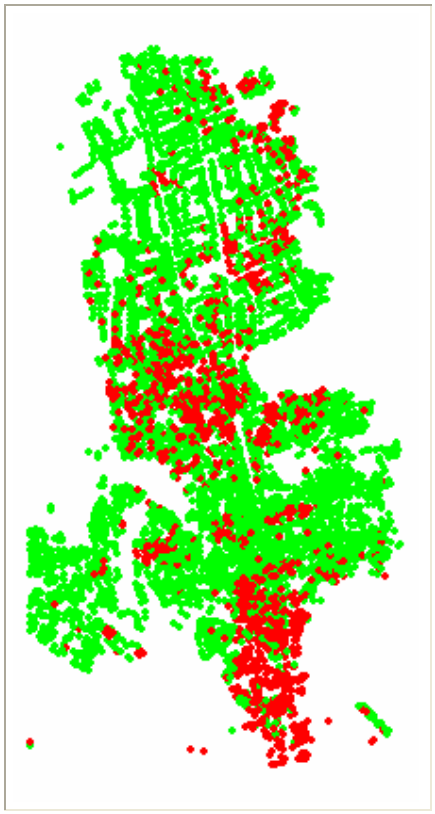
User List ID	Size	Required Coverage	Actual Coverage	Required Diversity	Actual Diversity	Required Service	Actual Service	Total Bandwidth	Total Revenue	Average Subscription
0	5381	0.500	0.650	0.000	0.650	0.000	0.596	1894112	2582880	0.32

Optimisation Tool Summary

Version number	4.040
Tool started at	23May06 - 12:24:12
Third stage algorithm	Tabu Search
Stage 1 proportionality value	0.500
Limiting number of Stage 2 iterations	500
Number of Stage 3 iterations	500
Statistics output	Reduced
Tabu Search recency list	Preserved
TS Neighbourhood Size	10
TS Recency List Length	10

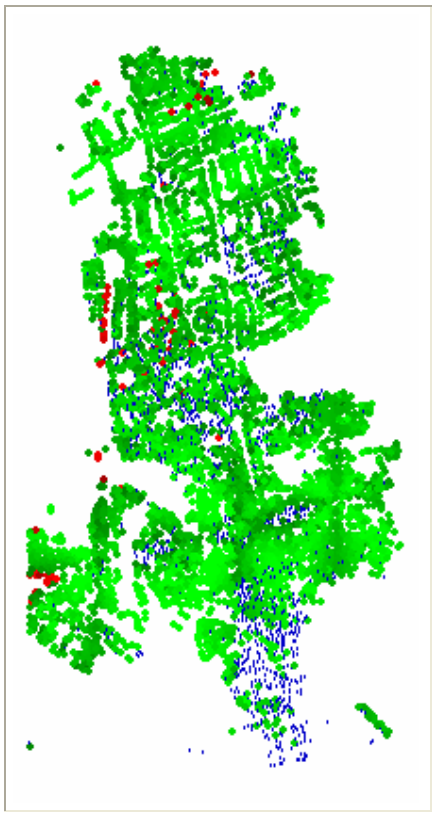


Cell Plan



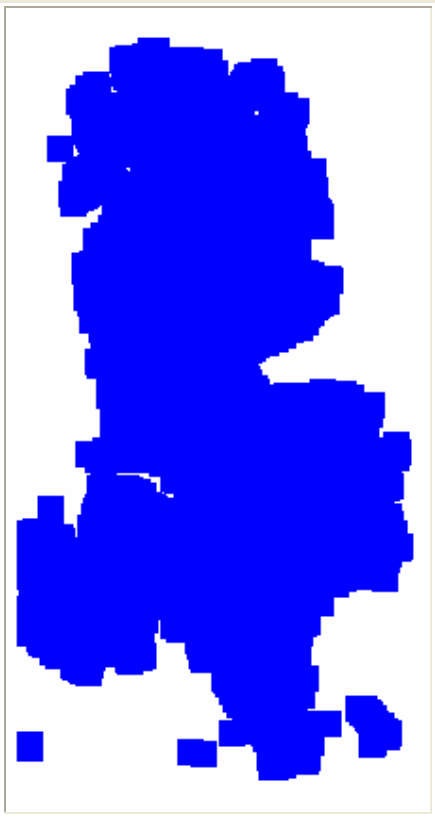
Coverage Indication

Diversity Map



C-I Indication

Service Indication



User Income Map

2.3.5 An NPV HTML File Example

Below we present an example of the Net Present Value calculation HTML file. The file is described in detail in section A.3.3

NPV Summary

Number of Periods	8
Number of Deployment periods	1
Number of User types	1

Period	0	1	2	3	4	5	6	7
Cumulative Discount	100%	89.2857%	79.7194%	71.178%	63.5518%	56.7427%	50.6631%	45.2349%

2.3.5.1 User Type: 0

Users of this type in the scenario: 5381

Period	0*	1	2	3	4	5	6	7
Take Rate	0.3	0.33	0.37	0.4	0.42	0.44	0.45	0.45
Market Share	0.7	0.7	0.6	0.55	0.5	0.5	0.5	0.5
Churn Rate	0.05	0.06	0.07	0.08	0.09	0.1	0.1	0.1
Revenue	480	390	360	330	300	300	300	300
Connection charge	50	55	60	65	70	70	70	70
Reqd Traffic	328	328	328	352	352	352	352	352
N_{Served}	3205	3205	3205	3205	3205	3205	3205	3205
N_{BOY}	0	673	740	711	705	673	705	721
N_{EOY}	673	740	711	705	673	705	721	721
N_{Ave}	336	706	725	708	689	689	713	721
N_{Chn}	0	40	51	56	63	67	70	72
N_{New}	673	107	22	50	31	99	86	72
$CAPEX_{EffAnt}$	100	75	56	42	32	25	25	25
$OPEX_{EffAnt}$	13	9	7	5	4	3	3	3
$CAPEX_{EffRTP}$	150	150	150	150	150	150	150	150
$OPEX_{EffRTP}$	0	0	0	0	0	0	0	0
Type Revenue	194930	281225	262320	236890	208870	213630	219920	221340
Type CapEx	168250	24075	4532	9600	5642	17325	15050	12600
Type OpEx	4368	6354	5075	3540	2756	2067	2139	2163

Base Station Data

Period	0*	1	2	3	4	5	6	7
Sites CapEx	150000	0	0	0	0	0	0	0
Sites OpEx	30000	26000	24000	20000	19000	17000	17000	17000
Sectors CapEx	110000	0	0	0	0	0	0	0
Sectors OpEx	5500	4774	4158	3630	3146	2750	2750	2750
Cash Flow	-273188	220022	224555	200120	178326	174488	182981	186827
Discounted Cash Flow	-273188	196448	179014	142441	113329	99009.2	92703.9	84511